



# Maxwell Air Force Base Thunderstorm Study

By  
Capt Robert J. Falvey



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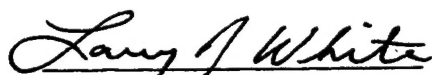
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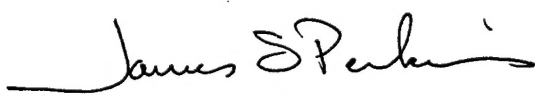
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13. Abstract: This technical note documents a study AFCCC completed to correlate various thunderstorm indices to the occurrence/non-occurrence of thunderstorms at Maxwell AFB, Ala. Eleven thunderstorm indices were calculated using unmodified and modified Centerville, Ala., upper-air data. Discriminate analysis techniques were used to determine statistically which, if any, of the indices could be used as predictors for occurrence/non-occurrence of thunderstorms. The discriminate functions were verified against an independent data set consisting of upper-air data from Centerville, Ala., and surface data from both Maxwell AFB, Ala., and Montgomery, Ala. Six different sets of classification tables based on probability thresholds were produced from the output of the discriminate functions. The regression equations developed are useful if they are used as a tool—not as a forecast. The unbinned modified sounding regression has high skill scores, a low false alarm rate, a low percent missed, and a high probability of detection.
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## PREFACE

This report documents the results of AFCCC (formerly USAFETAC) Project 9411010, accomplished in response to a request from the 42nd OSS/OSFW at Maxwell AFB, Ala. The requester asked AFCCC to correlate various thunderstorm indices to the occurrence/non-occurrence of thunderstorms in order to improve their forecasting capability. The request was subsequently modified to include regression equations that provide probability forecast guidance and 80th percentile threshold values of each index. Thunderstorm prediction continues to be an important and challenging aspect of operational aviation forecasting in the military. Most of research and investigation has been devoted to forecasting the intensity of thunderstorms—not whether or not thunderstorms will occur at a given location. This has left the forecaster with the tools to forecast how severe the thunderstorm would be if it were to happen and nothing to guide them on how to forecast whether or not thunderstorms will occur. This study was an attempt to provide a tool to this end, using standard thunderstorm indices.

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## Chapter 1

## INTRODUCTION

**1.1 Background.** The Maxwell AFB weather unit provides weather support for a wide variety of customers. From May to October, air mass thunderstorms have a negative impact on these customer's operations. Since accurate thunderstorm forecasting is crucial to all activities at Maxwell AFB, the local weather unit tasked AFCCC to correlate standard thunderstorm and stability indices to the occurrence/non-occurrence of air mass thunderstorms. The indices were calculated first using the 1200Z Centerville, Ala., sounding, and then using the same sounding modified at the surface by the 1800Z Maxwell AFB observation. Additionally, the 80th percentile for these indices was calculated.

Initial investigation into the correlation quickly showed very low correlation between the indices and the occurrence/non-occurrence of thunderstorms. This is primarily due to the fact that most of the indices were developed to determine the severity of thunderstorms, rather than to determine whether or not they will occur. After consulting with the requester, the original request for correlation was changed to regression analysis to provide probability of occurrence information.

## 1.2 Components of the Study.

**1.2.1 Data Extraction.** The data used in this study consisted of the 1200Z upper-air observations from Centerville, Ala., (Block Station Number 722290), and surface observations from Maxwell AFB (Block Station Number 722265) and Montgomery, Ala., (Block Station Number 722260). Maxwell AFB 1800Z surface observations were used to modify the Centerville upper-air data. Maxwell AFB and Montgomery surface observations between 1600Z and 0200Z were used to verify the occurrence/non-occurrence of thunderstorms. The period of record (POR) for the study was May through October for the years 1982 to 1992. The requester asked that 1993 be used as the verification year, but the POR from 1975 to 1981 was used to ensure a statistically significant sample size.

**1.2.2 Sounding Modification.** The raw upper-air data was quality controlled, preprocessed, and interpolated every 1,000 feet from the surface to 40,000 feet. The interpolation was needed in order to ensure the most accurate analysis and to facilitate the use of a FORTRAN version of the Skew-T Hodograph Analysis and Research Program (SHARP) routines to calculate the indices. The use of SHARP code was convenient and applicable since the requester routinely uses the MS-DOS version of the SHARP program to calculate thunderstorm indices. The 1800Z Maxwell surface observation of temperature and dew point was substituted for the surface values of temperature and dew point in the upper-air data. No other modifications were made.

**1.2.3 Indices Calculation.** Eleven thunderstorm indices were calculated using the unmodified and modified Centerville upper-air data. In both calculations, the lowest kilometer (approximately 3,282 feet) was mixed and any super-adiabatic lapse rates were eliminated by changing the lower-level data to dry adiabatic from the surface to the first point of intersection with the actual temperature curve. The indices calculated include: convectively available potential energy (CAPE), cap or lid strength, mean surface to 900 mb relative humidity (MeanRH), 700-500mb lapse rate (LAPS75), lifted index (LI), vertical totals (VT), cross totals (CT), total totals (TT), K-index (KI), Showalter stability index (SSI), and severe weather threat index (SWEAT).

**1.2.4 Discriminate Analysis.** Discriminate analysis techniques were used to determine statistically which, if any, of the indices could be used as predictors for the occurrence/non-occurrence of thunderstorms. In order to perform the discriminate analysis, the upper-air data was classified into thunderstorm (category 1) and non-thunderstorm (category 0) days based on the observational data from Maxwell AFB and Montgomery for the same day between 1600Z and 0200Z. Once the data was classified, the STEPWISE procedure from the Statistical Analysis System (SAS) software package was used to determine the best



## Chapter 1

indices to use in the discriminate analysis as predictors of thunderstorm occurrence/non-occurrence. The DISCRIM procedure was then used to develop a model, or discriminate function, that could be used to assign the probability of the occurrence/non-

occurrence of thunderstorms. This model was verified using an independent data set. Finally, the 80th percentile of each of the indices was calculated. This provides information, for example, that 80 percent of the thunderstorm days had  $CAPE \geq 3675$ .

## Chapter 2

## DISCRIMINATE ANALYSIS

**2.1 Introduction.** Discriminate analysis classifies individual observations into groups. It is a supervised classification in that the groups where the observations end up are pre-identified. In this study, the groups are defined as a "Yes" or "No" classification of the occurrence of thunderstorms.

**2.2 Methodology.** As was mentioned in Chapter 1, two independent data sets were used for this study. The analysis portion used data from May through October, from the POR 1982 to 1992. Indices were calculated from the unmodified and modified upper-

air data and are treated independently. Some of the indices have large ranges (CAPE can span three orders of magnitude); therefore, a binning technique was developed to assist in the discriminate analysis. Four discriminate functions were developed. The data used in these four functions include: the unbinned indices from the unmodified upper-air data; the unbinned indices from the modified upper-air data; the binned indices from the unmodified upper-air data; and the binned indices from the modified upper-air data. The variables used in each function are different. Table 1 shows the bins used for each of the indices.

**Table 1.** Thunderstorm index binning scheme used in the discriminate analysis.

Bin #	CAPE	CAP	Sweat	MeanRH	Laps75	LI	VT	CT	TT	KI	SSI
1	0000 - 1000	0 - 1	> 475	0 - 30	0 - -3	19 - 50	0 - 13	> 30	> 65	> 45	> 45
2	1000 - 2000	1 - 2	425 - 475	30 - 40	-3 - -4	16 - 19	13 - 16	25 - 30	60 - 65	35 - 45	40 - 45
3	2000 - 3000	2 - 3	375 - 425	40 - 50	-4 - -5	13 - 16	16 - 19	20 - 25	55 - 60	25 - 35	35 - 40
4	3000 - 4000	3 - 4	325 - 375	50 - 60	-5 - -6	10 - 13	19 - 22	15 - 20	50 - 55	15 - 25	30 - 35
5	4000 - 5000	4 - 5	275 - 325	60 - 70	-6 - -7	7 - 10	22 - 25	10 - 15	45 - 50	5 - 15	25 - 30
6	5000 - 6000	5 - 6	225 - 275	70 - 80	-7 - -8	4 - 7	25 - 28	5 - 10	40 - 45	-5 - 5	20 - 25
7	6000 - 7000	6 - 7	175 - 225	80 - 90	-8 - -9	1 - 4	28 - 31	0 - 5	35 - 40	-15 - -5	15 - 20
8	7000 - 8000	7 - 8	125 - 175	90 - 100	< -9	-2 - 1	31 - 33	-5 - 0	30 - 35	-25 - -15	10 - 15
9	> 8000	8 - 9	75 - 125			-5 - -2	33 - 36	-10 - -5	25 - 30	-35 - -25	5 - 10
10		9 - 10	25 - 75			-8 - -5	> 36	< -10	20 - 25	-45 - -35	0 - 5
11		10 - 11	< 25			-11 - -8			15 - 20	< -45	-5 - 0
12						< -11			10 - 15		-10 - -5
13									< 10		< -10

**2.3 Predictor Variables.** In order to determine which variables are the best predictors to use in the discriminate analysis, a stepwise selection was employed. This procedure uses analysis of variance techniques to examine individual and groups of data to determine the best possible combination.

**2.3.1 Unmodified Upper-air Indices.** The stepwise analysis determined seven predictor variables provided the best combination for the binned indices and five predictor variables for the unbinned indices for the unmodified upper-air case. The binned predictors used were K-index (KI), CAPE, cross totals

(CT), lifted index (LI), SWEAT Index, cap or lid strength, and vertical totals (VT). The unbinned predictors used were CAPE, surface to 900 mb mean relative humidity (MEANRH), total totals (TT), KI, and CT. These predictor variables were then used in the discriminate analysis to generate the discriminate function or regression equation.

**2.3.2 Modified Upper-air Indices.** The stepwise analysis determined four predictor variables provided the best combination for the binned indices and four predictor variables for the unbinned indices for the unmodified upper-air case. The binned predictors used

## Chapter 2

were KI, CAPE, CT, and SWEAT Index. The unbinned predictors used were CAPE, 700-500 mb lapse rate (LAPS75), TT, and KI.

**2.4 Discriminate Function.** The discriminate functions were computed using the predictor variables determined in the stepwise analysis. The functions consist of a constant and a coefficient multiplied by each of the predictor variables. An example PROC DISCRIM statement used to generate the discriminate function is shown below. The procedure call uses a data set called indices as input, which contains either the unbinned value or the binned value of the indices and an indicator, class=trwcode, that indicates if that day is or is not a thunderstorm day. The pool=yes option forces the procedure to use the pooled covariance matrix as a measure of generalized squared distance. The var= statement tells the procedure which variables (indices) to use in the discriminate function.

```
proc discrim data=indices pool=yes;
class=trwcode;
var=ki cape ct sweat;
run;
```

Once the discriminate function is defined, Equation 1 is used to calculate the probability (P) of thunderstorms. In order to calculate P, two coefficients, A and B, must be calculated. These

coefficients are computed for each separate discriminate function as described below.

$$P = [e^{(A \cdot B)} + 1]^{-1} \quad (1)$$

**2.4.1 Unmodified Discriminate Function Description.** The two coefficients for the unmodified, unbinned discriminate function are calculated using Equations 2 and 3. Likewise, the two coefficients for the unmodified binned discriminate function are calculated using Equations 4 and 5.

**2.4.2 Modified Discriminate Function Description.** The two coefficients for modified unbinned discriminate function are calculated using Equations 6 and 7. Likewise, the two coefficients for the modified binned discriminate function are calculated using Equations 8 and 9.

**2.5 Classification Summary.** The analysis dataset contained pairs of surface and upper-air observations. Tables 2 through 5 show the classification summary for this "calibration" data. To generate the classification summary, the analysis data set was resubstituted into the discriminate function that was developed from the analysis data set. These contingency tables show the number of occurrences and percentages of thunderstorms that were forecast and observed. Table 6 summarizes the percent correct,

$$A = -105.39698 - 0.00321 \cdot \text{CAPE} + 0.91225 \cdot \text{MEANRH} + 6.58412 \cdot \text{TT} - 0.55431 \cdot \text{KI} - 6.63435 \cdot \text{CT} \quad (2)$$

$$B = -109.09721 - 0.00284 \cdot \text{CAPE} + 0.92301 \cdot \text{MEANRH} + 6.66081 \cdot \text{TT} - 0.49578 \cdot \text{KI} - 6.76192 \cdot \text{CT} \quad (3)$$

$$A = -70.19581 + 3.68631 \cdot \text{KI} - 1.7549 \cdot \text{CAPE} + 2.49144 \cdot \text{CT} + 7.2467 \cdot \text{LI} + 5.54527 \cdot \text{SWEAT} - 1.08803 \cdot \text{CAP} + 5.44401 \cdot \text{VT} \quad (4)$$

$$B = -70.47095 + 3.15543 \cdot \text{KI} - 1.44857 \cdot \text{CAPE} + 2.85664 \cdot \text{CT} + 7.38063 \cdot \text{LI} + 5.321 \cdot \text{SWEAT} - 1.13132 \cdot \text{CAP} + 5.61748 \cdot \text{VT} \quad (5)$$

$$A = -44.41068 - 0.0006132 \cdot \text{CAPE} - 12.27451 \cdot \text{LAPS75} + 0.42561 \cdot \text{TT} + 0.13604 \cdot \text{KI} \quad (6)$$

$$B = -46.00232 - 0.0003864 \cdot \text{CAPE} - 12.5575 \cdot \text{LAPS75} + 0.36563 \cdot \text{TT} - 0.6864 \cdot \text{KI} \quad (7)$$

$$A = -22.42869 + 0.8227 \cdot \text{KI} + 1.80161 \cdot \text{CAPE} - 0.63756 \cdot \text{CT} + 4.88022 \cdot \text{SWEAT} \quad (8)$$

$$A = -21.03699 + 0.31079 \cdot \text{KI} + 2.01024 \cdot \text{CAPE} - 0.34071 \cdot \text{CT} + 4.65047 \cdot \text{SWEAT} \quad (9)$$

percent incorrect, percent missed, and false alarm rate for each of the classifications for the "calibration" data

set. A similar table will be shown in Chapter 3 for the verification data set.

**Table 2.** Classification table for binned unmodified upper-air data

OBSERVED	FORECAST		Total
	NO	YES	
NO	887	420	1307
	67.87	32.13	100.00
YES	73	309	382
	19.11	80.89	100.00
Total	960	729	1689
Percent	56.84	43.16	100.00

**Table 4.** Classification table for binned modified upper-air data.

OBSERVED	FORECAST		Total
	NO	YES	
NO	848	457	1305
	64.98	35.02	100.00
YES	67	315	382
	17.54	82.46	100.00
Total	915	772	1687
Percent	54.24	45.76	100.00

**Table 3.** Classification table for unbinned unmodified upper-air data.

OBSERVED	FORECAST		Total
	NO	YES	
NO	922	408	1330
	69.32	30.68	100.00
YES	75	316	391
	19.18	80.82	100.00
Total	1094	627	1721
Percent	63.57	36.43	100.00

**Table 5.** Classification table for unbinned modified upper-air data.

OBSERVED	FORECAST		Total
	NO	YES	
NO	876	452	1328
	65.96	34.04	100.00
YES	68	323	391
	17.39	82.61	100.00
Total	944	775	1719
Percent	54.92	45.08	100.00

**Table 6.** Statistical summary for the calibration data showing percent correct, percent incorrect, percent missed, and false alarm rate.

CLASSIFICATION	CORRECT	INCORRECT	MISSED	FALSE ALARM
UNMODIFIED/UNBINNED	71.9%	28.1%	19.2%	56.4%
UNMODIFIED/BINNED	70.8%	29.2%	19.1%	57.6%
MODIFIED/UNBINNED	69.7%	30.3%	17.4%	58.3%
MODIFIED/BINNED	68.9%	31.1%	17.5%	59.2%

## Chapter 3

## VERIFICATION

**3.1 Verification Procedure.** The discriminate functions were verified against an independent data set consisting of upper-air data from Centerville, Ala., and surface data from both Maxwell AFB and Montgomery, Ala. May through October were used over the POR 1975 through 1981. The procedure used was: (1) plug in the values of the appropriate indices into the corresponding coefficient equations (Equations 2-9), and (2) plug those coefficients into the discriminate function (Equation 1). An example calculation for a thunderstorm day in June 1977 for the unmodified binned case is shown below (refer to Equations 1, 4, and 5) for the following input data: KI = 32.3 or bin 3, CAPE = 6093.6 or bin 7, CT = 21.2 or bin 3, LI = -5.9 or bin 10, SWEAT = 184.8 or bin 7, CAP = 6.1 or bin 7, and VT = 27.5 or bin 6. Refer to Table 1 for the binning categories.

$$A = -70.19581 + (3.68631 \cdot 3.0) - (1.7549 \cdot 7.0) + (2.49144 \cdot 3.0) + (7.2467 \cdot 10.0) + (5.54527 \cdot 7.0) - (1.08803 \cdot 7.0) + (5.44401 \cdot 6.0) = 72.38488$$

$$B = -70.47095 + (3.15543 \cdot 3.0) - (1.44857 \cdot 7.0) + (2.85664 \cdot 3.0) + (7.38063 \cdot 10.0) + (5.321 \cdot 7.0) - (1.13132 \cdot 7.0) + (5.61748 \cdot 6.0) = 74.26421$$

$$P = 1 / [\exp(72.38488 - 74.26421) + 1] = 0.868 \text{ or } 86.8 \text{ percent}$$

**Table 7.** Classification table for binned unmodified upper-air data (50 percent).

FORECAST	OBSERVED		Total
	NO	YES	
NO	616	111	727
	84.73	15.27	100.00
YES	250	177	427
	58.55	41.45	100.00
Total	866	288	1154
Percent	75.04	24.96	100.00

**Table 9.** Classification table for binned modified upper-air data (50 percent).

FORECAST	OBSERVED		Total
	NO	YES	
NO	619	114	733
	84.45	15.55	100.00
YES	244	174	418
	58.37	41.63	100.00
Total	863	288	1151
Percent	74.98	25.02	100.00

Contingency tables for each classification were generated using Equations 1 through 9 for each day of the verification POR and are summarized in Tables 7 through 30.

**3.2 Verification Results.** Six different sets of classification tables were produced from the output of the discriminate function. The output from Equation 1 is a number between 0 and 1, which corresponds to the probability between 0 and 100 percent that thunderstorms are forecast to occur. Six probability thresholds were examined in order to look at the relationship between correct forecasts, incorrect forecasts, false alarm rates, and probability of detection. These probability thresholds were used to determine whether the discriminant function forecast thunderstorms to occur ("yes") or not ("no"). For example, in the first set of tables (Tables 7-10), if the probability from the discriminate equation was greater than or equal to 0.5 or 50 percent chance, the forecast was a "yes" and below 0.5 the forecast was a "no". The remaining tables (11-30) use higher probability thresholds incrementally from 0.55 to 0.75 by 0.05 (55 to 75 percent every 5 percent). The data from these tables can be used to calculate measures of skill.

**Table 8.** Classification table for unbinned unmodified upper-air data (50 percent).

FORECAST	OBSERVED		Total
	NO	YES	
NO	783	217	1000
	78.3	21.7	100.00
YES	83	71	154
	53.90	46.1	100.00
Total	866	288	1154
Percent	75.04	24.96	100.00

**Table 10.** Classification table for unbinned modified upper-air data (50 percent).

FORECAST	OBSERVED		Total
	NO	YES	
NO	615	106	721
	85.30	14.70	100.00
YES	248	182	430
	57.67	42.33	100.00
Total	863	288	1151
Percent	74.98	25.02	100.00

**Table 11.** Classification table for binned unmodified upper-air data (55 percent).

FORECAST	OBSERVED		Total
	NO	YES	
NO	673	137	810
	83.09	16.91	100.00
YES	193	151	427
	56.10	43.90	100.00
Total	866	288	1154
Percent	75.04	24.96	100.00

**Table 13.** Classification table for binned modified upper-air data (55 percent).

FORECAST	OBSERVED		Total
	NO	YES	
NO	664	135	799
	83.10	16.90	100.00
YES	199	153	352
	56.53	43.47	100.00
Total	863	288	1151
Percent	74.98	25.02	100.00

**Table 15.** Classification table for binned unmodified upper-air data (60 percent).

FORECAST	OBSERVED		Total
	NO	YES	
NO	709	160	869
	81.59	18.41	100.00
YES	157	128	285
	55.09	44.91	100.00
Total	866	288	1154
Percent	75.04	24.96	100.00

**Table 17.** Classification table for binned modified upper-air data (60 percent).

FORECAST	OBSERVED		Total
	NO	YES	
NO	704	157	861
	81.77	18.23	100.00
YES	159	131	290
	54.83	45.17	100.00
Total	863	288	1151
Percent	74.98	25.02	100.00

**Table 12.** Classification table for unbinned unmodified upper-air data (55 percent).

FORECAST	OBSERVED		Total
	NO	YES	
NO	807	232	1039
	77.7	22.3	100.00
YES	59	56	115
	51.3	48.7	100.00
Total	866	288	1154
Percent	75.04	24.96	100.00

**Table 14.** Classification table for unbinned modified upper-air data (55 percent).

FORECAST	OBSERVED		Total
	NO	YES	
NO	667	124	791
	84.32	15.68	100.00
YES	196	164	360
	54.44	45.56	100.00
Total	863	288	1151
Percent	74.98	25.02	100.00

**Table 16.** Classification table for unbinned unmodified upper-air data (60 percent).

FORECAST	OBSERVED		Total
	NO	YES	
NO	828	238	1066
	77.7	22.3	100.00
YES	38	50	88
	43.2	56.8	100.00
Total	866	288	1154
Percent	75.04	24.96	100.00

**Table 18.** Classification table for unbinned modified upper-air data (60 percent).

FORECAST	OBSERVED		Total
	NO	YES	
NO	705	144	849
	83.04	16.96	100.00
YES	158	144	302
	52.32	47.68	100.00
Total	863	288	1151
Percent	74.98	25.02	100.00

**Table 19.** Classification table for binned unmodified upper-air data (65 percent).

FORECAST	OBSERVED		Total
	NO	YES	
NO	752	193	945
	79.58	20.42	100.00
YES	114	92	206
	55.34	44.66	100.00
Total	866	288	1154
Percent	75.04	24.96	100.00

**Table 20.** Classification table for unbinned unmodified upper-air data (65 percent).

FORECAST	OBSERVED		Total
	NO	YES	
NO	837	262	1099
	76.2	23.8	100.00
YES	29	26	55
	52.7	47.3	100.00
Total	866	288	1154
Percent	75.04	24.96	100.00

**Table 21.** Classification table for binned modified upper-air data (65 percent).

FORECAST	OBSERVED		Total
	NO	YES	
NO	756	193	949
	79.66	20.34	100.00
YES	107	95	202
	52.97	47.03	100.00
Total	863	288	1151
Percent	74.98	25.02	100.00

**Table 22.** Classification table for unbinned modified upper-air data (65 percent).

FORECAST	OBSERVED		Total
	NO	YES	
NO	740	184	924
	80.09	19.91	100.00
YES	123	104	227
	54.19	45.81	100.00
Total	863	288	1151
Percent	74.98	25.02	100.00

**Table 23.** Classification table for binned unmodified upper-air data (70 percent).

FORECAST	OBSERVED		Total
	NO	YES	
NO	786	217	1003
	78.36	21.64	100.00
YES	80	71	151
	52.98	47.02	100.00
Total	866	288	1154
Percent	75.04	24.96	100.00

**Table 24.** Classification table for unbinned unmodified upper-air data (70 percent).

FORECAST	OBSERVED		Total
	NO	YES	
NO	849	269	1118
	75.9	24.1	100.00
YES	17	19	36
	47.2	52.8	100.00
Total	866	288	1154
Percent	75.04	24.96	100.00

**Table 28.** Classification table for binned modified upper-air data (70 percent).

FORECAST	OBSERVED		Total
	NO	YES	
NO	794	218	1012
	78.46	21.54	100.00
YES	69	70	139
	49.64	50.36	100.00
Total	863	288	1151
Percent	74.98	25.02	100.00

**Table 28.** Classification table for unbinned modified upper-air data (70 percent).

FORECAST	OBSERVED		Total
	NO	YES	
NO	790	221	1011
	78.14	21.86	100.00
YES	73	67	140
	52.14	47.86	100.00
Total	863	288	1151
Percent	74.98	25.02	100.00



**Table 27.** Classification table for binned unmodified upper-air data (75 percent).

FORECAST	OBSERVED		Total
	NO	YES	
NO	812	234	1046
	77.63	22.37	100.00
YES	54	54	108
	50.00	50.00	100.00
Total	866	288	1154
Percent	75.04	24.96	100.00

**Table 29.** Classification table for binned modified upper-air data (75 percent).

FORECAST	OBSERVED		Total
	NO	YES	
NO	827	248	1075
	76.93	23.07	100.00
YES	36	40	76
	47.37	52.63	100.00
Total	863	288	1151
Percent	74.98	25.02	100.00

**3.3 Skill Scores.** Table 32 summarizes skill scores for six different probability thresholds described in section 3.2. These measures of skill include percent correct, percent incorrect, probability of detection (POD), percent missed, false alarm rate (FAR), the Heidke Skill Score (HSS), and the Hanssen and Kuipers Discriminate "V" (HKDV). Equations 10 through 16 are used to calculate measures of skill (using the parameters A, B, C, and D defined in Table 31). The percent correct is simply the sum of the yes forecast/yes observed and the no forecast/no observed divided by the total number of forecast made. The percent incorrect is one minus the percent correct. The probability of detection is the yes forecast/yes observed divided by the sum of the yes forecast/yes observed and the no forecast/yes observed. The percent missed is the no forecast/yes observed divided by the total number of event days (no forecast/yes observed + yes forecast/yes observed). The false alarm rate is the number of yes forecast/no observed divided

**Table 28.** Classification table for unbinned unmodified upper-air data (75 percent).

FORECAST	OBSERVED		Total
	NO	YES	
NO	834	277	1131
	75.5	24.5	100.00
YES	12	11	23
	52.2	47.8	100.00
Total	866	288	1154
Percent	75.04	24.96	100.00

**Table 30.** Classification table for binned unmodified upper-air data (75 percent).

FORECAST	OBSERVED		Total
	NO	YES	
NO	820	248	1068
	76.78	23.22	100.00
YES	43	40	83
	51.81	48.19	100.00
Total	863	288	1151
Percent	74.98	25.02	100.00

by the sum of yes forecast/yes observed and yes forecast/no observed. The Heidke Skill Score and the Hanssen and Kuipers Discriminate "V" are calculated using Equation 15 and 16, respectively. The Heidke Skill Score and the Hanssen and Kuipers Discriminate "V" assess the skill of the forecast method to that of chance. The range of these measures is from -1 (no skill) to +1 (perfect skill). A score of zero implies that the method is no better than chance.

**Table 31.** Contingency Table.

		OBSERVED	
		NO	YES
F O R E C A S T	N O	# of occurrences (A)	# of occurrences (B)
	Y E S	# of occurrences (C)	# of occurrences (D)



The ideal situation would be to maximize the percent correct and the probability of detection, while minimizing the percent missed and false alarm rate. From this table, a trend is evident: as the probability threshold increases from 50 percent to 75 percent, the false alarm rate decreases, but the probability of detection decreases and the percent missed increases. This trend is understandable since by using a higher probability threshold, the yes forecasts that are made

are more likely to verify because the weather conditions more clearly indicate the formation of thunderstorms. However, this causes the thunderstorms that occur in the lower probability threshold region to be missed. Thus, the probability of detection decreases and the missed forecasts increases. It is left to the user to define an acceptable balance of these parameters.

$$\text{Percent Correct} = \frac{A+D}{(A+B+C+D)} \quad (10)$$

$$\text{Percent Missed} = \frac{B}{(B+D)} \quad (13)$$

$$\text{Percent Incorrect} = \frac{B+C}{(A+B+C+D)} \quad (11)$$

$$\text{FAR} = \frac{C}{(C+D)} \quad (14)$$

$$\text{Probability of Detection} = \frac{D}{(B+D)} \quad (12)$$

$$\text{HSS} = \frac{2(AD-BC)}{(B+D)(B+A)+(C+D)(A+D)} \quad (15)$$

$$\text{HKDV} = \frac{AD-BC}{(B+D)(A+C)} \quad (16)$$

**Table 32.** Summary of skill table showing the forecast threshold, percent correct, percent incorrect, probability of detection, percent missed, false alarm rate, Heidke skill score, and Hanssen and Kuipers Discriminate.

index/sounding	Threshold	% Correct	% Incorrect	POD	% Missed	FAR	HSS	HKDV
unbinned/unmodified	50%	74.0	26.0	24.7	75.3	38.2	0.18	0.151
	55%	74.8	25.2	19.4	80.6	43.9	0.16	0.126
	60%	76.1	23.9	17.4	82.6	44.9	0.17	0.130
	65%	74.8	25.2	9.0	91.0	41.2	0.08	0.057
	70%	75.2	24.8	6.6	93.4	40.0	0.07	0.046
	75%	75.0	25.0	3.8	96.2	25.0	0.04	0.024
unbinned/modified	50%	69.2	30.8	63.2	36.8	57.7	0.30	0.345
	55%	72.2	27.8	56.9	43.1	54.4	0.32	0.342
	60%	73.8	26.2	50.0	50.0	52.3	0.31	0.317
	65%	73.3	26.7	36.1	63.9	54.2	0.24	0.219
	70%	74.5	25.5	23.3	76.6	52.1	0.18	0.148
	75%	74.7	25.3	13.9	86.1	51.8	0.12	0.089
binned/unmodified	50%	68.7	31.3	61.5	38.5	58.5	0.28	0.326
	55%	71.4	28.6	52.4	47.6	56.1	0.28	0.301
	60%	72.5	27.5	44.4	55.6	55.1	0.26	0.263
	65%	73.1	26.9	31.9	68.1	55.3	0.21	0.188
	70%	74.3	25.7	24.7	75.3	53.0	0.18	0.154
	75%	75.0	25.0	18.8	81.3	50.0	0.16	0.125
binned/modified	50%	68.9	31.1	60.4	39.6	58.4	0.28	0.321
	55%	71.0	29.0	53.1	46.9	56.5	0.28	0.301
	60%	72.5	27.5	45.5	54.5	54.8	0.27	0.271
	65%	73.9	26.1	33.0	67.0	53.0	0.23	0.206
	70%	75.1	24.9	24.3	75.7	49.6	0.20	0.163
	75%	75.3	24.7	13.9	86.1	47.4	0.13	0.097

## Chapter 4

## SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

**4.1 Summary.** Thunderstorm prediction continues to be an important and challenging aspect of operational aviation forecasting in the military. Most of research and investigation has been devoted to forecasting the intensity of thunderstorms—not whether or not thunderstorms will occur at a given location. This has left the forecaster with the tools to forecast how severe the thunderstorm would be if it were to happen, but nothing to guide them on how to forecast whether or not thunderstorms will occur. This study was an attempt to provide a tool to this end, using standard thunderstorm indices. Initial investigation into correlation data between the occurrence/non-occurrence of thunderstorms with eleven thunderstorm indices showed little to no correlation. Therefore, a different approach was used. Discriminate analysis was used to develop regression equations relating the severe thunderstorm indices to the occurrence/non-occurrence of thunderstorms. These equations provide the forecaster a statistical probability of occurrence of thunderstorms.

**4.2 Conclusion.** The regression equations developed to provide forecast guidance should prove to be useful if they are used as a tool—not as the forecast. As with any other tool, the probability output from the regression equation needs to be melded into the forecasters decision-making process to make the best

possible forecast. This is especially true given the values of the skill scores. The combination with the best skill is the unbinned modified sounding regression equation using the 55 percent forecast threshold. However, the probability of detection decreases and the percent missed increases as you move away from the 50 percent forecast threshold. There are other very important factors and conditions that should be included in the thunderstorm forecast, such as the occurrence of thunderstorms the previous day and the type of air mass that exists.

**4.3 Recommendations.** Close examination of Table 32 shows the trade-offs between the percent correct forecasts and the percent of missed events and the false alarm rate. Operational forecasters typically err on the conservative side. That is to say, a higher false alarm rate is usually preferred to a higher percent missed rate. Therefore, it is recommended that the 50 percent threshold be used as a yes/no breakpoint. This will minimize the percent missed and the false alarm rate, while maximizing the probability of detection. Additionally, from the skill scores in Table 32, the 50 percent threshold shows the most skill. The best combination to use is the unbinned modified sounding regression equation. It has high skill scores, a low false alarm rate, a low percent missed, and a high probability of detection.

## GLOSSARY

**CAPE:** Convectively Available Potential Energy (CAPE) is an index that measures the positive area on the Skew-T Log P diagram. It is calculated by finding the lifted condensation level (LCL) and lifting that parcel moist adiabatically through the level of free convection (LFC) to the Equilibrium Level. The area between this path and the actual environmental temperature trace is the CAPE.

**Cap:** Cap or lid strength is the difference between buoyancy strength and the inversion strength. The buoyancy strength is defined as the difference between the mean wet-bulb potential temperature in the lowest 50 millibars and the mean saturation wet-bulb potential temperature between the inversion and the 500 millibar level. The inversion strength is defined as the difference between the maximum saturation wet-bulb potential temperature at the inversion level and the mean wet-bulb potential temperature in the lowest 50 millibars.

**MEANRH:** MEANRH is the mean relative humidity between the surface and the 900 millibar level.

**LAPS75:** LAPS75 is the lapse rate calculated between 700 millibars and 500 millibars.

**LI:** LI is an acronym that stands for lifted index. The lifted index is defined as the temperature difference between the environment and a parcel of air that has been lifted moist adiabatically from the LCL to 500 millibars.

**VT:** VT is a an acronym that stands for vertical totals. It is calculated by finding the temperature difference between 850 millibars and 500 millibars.

**CT:** CT is a an acronym that stands for Cross Totals. It is calculated by finding the difference between the dew point temperature at 850 millibars and the ambient temperature at 500 millibars.

**TT:** TT is a an acronym that stands for Total Totals. It is calculated by summing the cross totals and the vertical totals.

**KI:** KI is a an acronym that stands for K-Index. It is derived mathematically and does not require a plotted sounding.

**SSI:** SSI is an acronym that stands for Showalter Stability Index. It is calculated by taking the difference between the ambient temperature at 500 millibars and the parcel temperature lifted moist adiabatically from the 850 millibar LCL to 500 millibars.

**SWEAT:** SWEAT is an acronym that stands for Severe Weather Threat index. The SWEAT index consists of a formula that uses five parameters that contribute to severe weather potential: low-level moisture (850 millibar dew point), instability (TT), low- and upper-level jet (850 and 500 millibar wind speeds), and warm advection (veering wind direction between 850 and 500 millibar levels), to calculate a score. Commonly accepted SWEAT index threshold values used by the Air Force are usually 300 for severe weather and 400 for tornadoes.

## ACRONABs

ACRONAB	Acronym or abbreviation
AFB	Air Force Base
AFCCC	Air Force Combat Climatology Center (formerly designated USAFETAC)
CAPE	Convectively Available Potential Energy
CT	Cross Totals
EL	Equilibrium Level
FAR	False Alarm Rate
GMT	Greenwich Mean Time
HKDV	Hanssen and Kuipers Discriminant V
HSS	Heidke Skill Score
KI	K-Index
LCL	Lifting Condensation Level
LFC	Level of Free Convection
LI	Lifted Index
POD	Probability Of Detection
POR	Period Of Record
SHARP	Skew-T Hodograph Analysis and Research Program
SSI	Showalter Stability Index
SWEAT	Severe Weather Threat
TT	Total Totals
USAFETAC	United States Air Force Environmental Technical Applications Center (renamed AFCCC)
VT	Vertical Totals

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